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RESEARCH MEMORANDUM

ANALYSIS OF MULTIENGINE TRANSPORT

AIRPLANE FIRE RECORDS

By Gerard J. Pesman

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

An analysis has been made of Civil Aeronautics Administration and Civil Aeronautics Board commercial airplane fire records collected during the 10-year period ending July 1, 1948. The results of the analysis show that:

1. Gasoline was most frequently the initial combustible ignited in flight and ground fires and is considered to be the most hazardous of the combustibles carried.

2. Although electrical-ignition sources are the most frequent flight-fire ignition source by a small margin, the exhaust system is concluded to be the most hazardous ignition source because it is necessarily located near the lubricating-oil and gasoline-plumbing systems and the resulting fires are relatively severe. The electrical-ignition sources usually involve only the electrical insulation and result in small-volume fires. The exhaust system was found to be the most frequent ground-fire ignition source.

3. Engine failures were the most frequent cause of the union of combustible and ignition source that resulted in flight fires.

4. Fuel-plumbing-system failures were the most frequent cause of fires occurring during ground operation.

5. The evidence concerning crash fires was not sufficiently extensive to provide information concerning the factors that affect the start and the spread of fire.

In order that future records may be more useful, all crash accidents should be studied to determine why fire does or does not occur and to establish data that relate the occurrence and the spread of fire to airplane design and operation.

INTRODUCTION

Further improvement in aircraft safety by reducing the possibility of fire is recognized as a desirable objective by the aviation industry. Achievement of this aim is of interest to both commercial and military operators. A significant reduction in the fire hazard requires the establishment of engineering design criterions that will result in the best possible fire prevention and personnel safety. The NACA aircraft-fire research program, in coordination with research and development by other governmental agencies and the aviation industry, is directed toward this objective.

One of the first steps in an attack on the airplane-fire problem should be a study of the records of past aircraft fires. The largest number of air-transport fire records immediately available were those collected by the Civil Aeronautics Administration and the Civil Aeronautics Board. The information contained in these records was submitted by air-transport operators when scheduled aircraft were forced to deviate from the published schedule because of malfunctioning or failure of a mechanical part or when an accident had occurred. The Civil Aeronautics Board records are predominantly those prepared following the investigation of serious accidents.

The records were studied to determine the relative frequency with which the various combustibles, ignition sources, and cause factors were involved in airplane fires so that remedial measures can be discovered and applied to those of first-order importance. The analysis covers 282 air-transport aircraft fires that occurred during the 10-year period ending July 1, 1948. The records analyzed include those of fires that occurred on air-transport-type airplanes being used for crew training and orientation purposes. (This study does not include phases of the fire problem arising from military combat operations.)

ANALYSIS OF RECORDS

Numerous combustibles are present in the various systems and components of the airplane; ignition sources either exist continuously or may be produced by malfunctioning or failure of mechanical and electrical systems; and the airplane operates in an atmosphere containing oxygen. All the components of fire are therefore present and need only be brought together for a fire to result. In a machine as intricate as the multiengine transport airplane with its numerous entwined and crowded mechanical and electrical systems, the malfunctioning, failure, mishandling, or maldesign of a single system

can easily cause the spilling of a combustible where it can reach an ignition source or the creation of an ignition source near a combustible and thus eventually result in fire. Such malfunctioning, failure, mishandling, or maldesign is then the primary cause of the fire. It is not to be expected, however, that the same primary causes will be responsible for fire in all phases of airplane operation nor that all combustibles or ignition sources will be involved with equal frequency. The air-flow conditions, the power output, and the physical integrity of the aircraft structure will depend on whether the cause for the fire occurs during ground operation, flight operation, or a crash. Thus, consideration of the factors involved in the mechanism of an aircraft fire indicate the desirability of knowing individually for flight, ground, and crash fires the relative frequency with which the various combustibles are initially involved, the relative frequency with which the various ignition sources are involved, the relative frequency with which the various systems malfunction and fail, and the prevalent combinations of combustible, ignition source, and malfunction or failure.

On the basis of these principles, the 282 cases were separated into ground, flight, and crash fire groups. The cases in each group were then analyzed to determine the relative frequencies with which each initial combustible, ignition source, and malfunction or failure was involved in a fire. The final step was to determine which combinations of combustible, ignition source, and malfunction were prevalent.

The proportional distribution of commercial transport fires with respect to the operational phase in which they occurred is shown in the following table:

Fires	Cases	Percent
Flight	135	48
Ground	82	29
Crash	61	$21\frac{1}{2}$
Unknown	4	$1\frac{1}{2}$
Total	282	

Although the table gives the relative frequency with which the fires occurred, it does not indicate the relative importance of each group

with respect to personnel fatalities or damage to the aircraft involved. Ground fires, although second in frequency, were rarely fatal to personnel and seldom resulted in more than minor structural damage to the aircraft and are therefore the least important. Any fire may easily escape control, however, and the potential losses due to ground fires should not be overlooked. Flight fires were frequently extinguished and resulted in minor damage and no loss of life, but at other times resulted in complete destruction of the aircraft and its occupants. Crash fires have usually been more severe than flight fires and there is indication that crash fires may have been responsible for a larger number of deaths (reference 1).

Combustibles. - The frequency with which the various inflammable materials serve as the initial combustible in flight fires is shown by the following table:

Initial combustible	Cases	Percent of known cases
Gasoline	30	27
Electrical insulation	30	27
Other solid	21	$19\frac{1}{2}$
Lubricating oil	17	$15\frac{1}{2}$
Gasoline or lubricating oil	9	8
Hydraulic fluid	3	3
Unknown	25	
Total	135	

The percentage figures show that gasoline and electrical insulation were involved with equal frequency. In order to obtain the true significance of gasoline as the initial combustible, however, part of the 8 percent listed under gasoline or lubricating oil (exact determination of initial combustible was impossible in the case of these engine-failure fires) must be added to the 27 percent for gasoline, thus making gasoline the most frequent initial combustible by a small margin. Furthermore, a study of the individual cases shows that more severe damage is associated with gasoline fires in flight than with electrical-insulation fires. Consequently, gasoline is concluded to be the most hazardous as well as the most frequent initial combustible.

Totaling of the various percentages shows that gasoline and lubricating oil are initially involved in half of all flight fires. Addition of the electrical insulation percentage brings the fraction to three-fourths of the total; thus the majority of all flight fires start with one of these three combustibles.

The miscellaneous solid combustibles included a wide range of materials, of which the following is a partial list: baggage, nap on cockpit lining, kapok insulation, oil hoses, cooking grease, heater ducts, rubber carburetor collar, magnesium generator shaft, paper towels, and seat upholstery. This wide range indicates that every combustible material used in aircraft construction or operation must be scrutinized as a possible fire hazard.

The frequency with which the inflammable materials serve as the initial combustible in ground fires is as follows:

Initial combustible	Cases	Percent of known cases
Gasoline	49	68
Electrical insulation	8	11
Lubricating oil	6	8 $\frac{1}{2}$
Hydraulic fluid	6	8 $\frac{1}{2}$
De-icing alcohol	2	3
Other solids	1	1
Unknown	<u>10</u>	
Total cases	82	

The results show that gasoline was most frequently the initial combustible. Additional study of the gasoline-fire data indicated that 40 of the 68 percent of these fires occurred during the engine-starting operation. Even if these fires are disregarded, the remaining percentage indicates that gasoline remains the most frequent initial combustible in ground fires, as was the case in flight fires.

Data for the study of crash fires were obtained predominantly from the reports of Civil Aeronautics Board accident investigations. Inasmuch as these investigations are usually made when an accident results in death or serious injury to personnel or considerable damage to the airplane, the data generally represent a more serious type of accident than the flight and ground fires and much of the evidence was destroyed by the resulting conflagration.

The initial-combustible data for crash fires are presented in the following table. The percentages have been calculated on the basis of the total number of cases because the number of known cases is too small to be significant.

Initial Combustible	Cases	Percent of total
Gasoline	6	10
Hydraulic fluid	1	$1\frac{1}{2}$
Unknown	54	$88\frac{1}{2}$
Total	61	

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A comparison of the percentage of fires that initially involved gasoline, 27 percent in flight and 68 percent on the ground, and consideration of the individual cases of flight and ground fires leads to the conclusion that gasoline is the most hazardous of the combustible materials involved in flight or ground fires. The partial indication given by the crash data plus consideration of gasoline characteristics gives no indication that the result would be markedly different for crash fires. Even when lubricating oil serves as a torch fire that ignites the bulk of the gasoline, the gasoline is responsible for the rapid spread of fire, the rapid increase in fire intensity, and the size of fire.

A comparison of the physical characteristics that affect the relative inflammability of the various liquids shows that, although gasoline has a slightly higher spontaneous ignition temperature (200°-300° F) it is much more volatile than either lubricating oil or hydraulic fluid. Thus the volatility of a combustible is apparently the most important factor in determining the fire hazard. The experience of commercial transport operators with Diesel engines indicates also that fuel volatility is an important factor in the fire hazard. The following quotation is from reference 2, page 192:

"There has yet to be recorded an accident where the fuel oil ignited and burned on a Diesel-engined airplane.

"In connection with lubricating oil fires, the experience of Deutsche Lufthansa with one of their Junkers Ju 52 airliners powered with three Junkers Jumo 205-C Diesels is of interest. While the airplane was flying in a fog, it

collided with a hill and cracked up and the entire supply of fuel oil was emptied over the wreckage. A lubricating oil fire broke out in the center engine and if the fuel had been gasoline, there can be little doubt but that the airplane would have burst into flames. The fuel oil did not catch fire, however, and one of the rescuers who hurried to the scene was able to quench the flames with an ordinary fire extinguisher."

This statement was written in 1940. The Junkers Jumo engine was placed in airline service about 1931 and the various models had been flown more than 59,000 hours by the end of 1938 (reference 2, p. 117); therefore, the experience cannot be considered insignificant.

Liquids such as lubricating oil and hydraulic fluid, with flash temperatures above ambient-air temperature, must reach an ignition source in liquid form. This situation can occur when the liquid is sprayed, splashed, or runs by gravity. With a material such as gasoline, which has a flash temperature well below normal ambient-air temperatures, the vapor is sufficiently concentrated that an inflammable mixture can easily be transported by air currents to an ignition source. Furthermore, gasoline crash fires are more difficult to extinguish than fires involving the less-volatile liquids (reference 1). Thus the conclusion that a highly volatile liquid such as gasoline is a hazardous aircraft fuel seems warranted.

Ignition sources. - For the discussion of ignition sources, the following definitions apply: Electrical ignition sources are considered to be electrical sparks or arcs and electrical equipment that is elevated to the ignition temperature of the combustibles by the passage of excessive current. A backfire is ignition and burning of a combustible mixture in the induction system at any position upstream of the intake valve. The miscellaneous ignition sources include matches, cigarettes, sliding friction, and sources not otherwise covered.

The relative importance of the ignition sources is shown in subsequent tables. The following table shows the frequency with which various ignition sources started flight fires:

Ignition source	Cases	Percent of known cases
Electrical	38	$38\frac{1}{2}$
Exhaust duct and gases	35	$35\frac{1}{2}$
Other miscellaneous	12	12
Backfire	7	7
Combustion heater	7	7
Unknown	36	
Total	135	

The percentages indicate that the exhaust duct and gases and the electrical sources of ignition started fires with approximately equal frequency. An understanding of the comparative significance of these two ignition sources, however, requires a more careful analysis than is possible by simply counting the incidents in which each is involved. The electrical power, communication, and instrument systems do not usually serve as ignition sources if properly enclosed, except when they are malfunctioning or being destroyed, and then are ignition sources for a comparatively short time. Investigation has shown (reference 3) that when a load-carrying conductor is short-circuited, the conductor most frequently burns through and opens the circuit and thus provides a potentially hazardous ignition source having a median life of only 0.6 second. The accident records show that electrical sources of ignition usually involve only the electrical insulation and result in small-volume fires. The conclusion is therefore reached that the hazard associated with electrical sources of ignition is not great, although one case in which electrical-equipment failure started a hydraulic-fluid fire did result in a serious accident.

The ignition source represented by the exhaust-duct system and the exhaust gases, however, continuously exists throughout powered flight. The exhaust-duct system occupies a large volume and is necessarily located close to the lubricating-oil and gasoline-plumbing systems, each of which can supply a considerable bulk of inflammable material. Exhaust-system ignited fires are consequently relatively severe, as shown by the flight-fire data. Considering the elapsed time of existence, volume occupied, proximity to bulk of combustible, and the generally minor damage of electrically ignited fires, it is concluded that the exhaust and its disposal system are the most hazardous flight-fire ignition sources. The frequency with which electrically ignited fires occur, however, indicate that the associated potential hazard should not be overlooked.

The miscellaneous ignition sources included matches, cigarettes, a galley heating element, friction, and the compression of gases on the discharge side of vacuum pumps.

The next table shows the frequency with which various ignition sources started ground fires.

Ignition source	Cases	Percent of known cases
Backfire	21	38
Exhaust system	17	31
Electrical ignition source	11	20
Combustion heater	5	9
Other	1	2
Unknown	27	
Total	82	

The 21 backfire-ignited ground fires, which constitute the largest group, include 19 cases in which gasoline was involved and two cases in which carburetor de-icing alcohol was ignited. The majority of these fires attended the starting operations. Although the percentages indicate that backfires were the most frequent ignition source, the frequency of such fires showed a decreasing trend not evident in items presented in previous tables. The frequency of exhaust-system ignited fires, however, increased more rapidly than the increase in revenue hours shown by reference 4. It is therefore apparent that the exhaust system is currently the most frequent ground-fire ignition source.

Crash-fire ignition-source data are summarized as follows:

Ignition source	Cases	Percent of total
Sliding friction	2	3
Unknown	59	97
Total	61	

The relative importance of the various possible crash-fire ignition sources is not shown by the data because too many cases were unknown. This high unknown percentage will be discussed subsequently.

Many potential ignition sources for crash fires exist: backfires, torching at exhaust-duct outlet, electrical-ignition sources

(arcs and short-circuited wiring), sliding friction, the hot metal of the exhaust-disposal system, and exhaust gases within the exhaust-disposal system. In general, all the aforementioned ignition sources except the exhaust-disposal system exist for short periods of time. The exhaust system, however, exists as a potential ignition source throughout the dynamic phases of a crash and for a considerable period thereafter. The British found (reference 5) that the exhaust-duct system was a serious ignition-source hazard and recommended that it be cooled or inerted. The U. S. Army Air Corps in a series of crash tests in 1924-25 with obsolete aircraft found that the exhaust stacks were the most important ignition source. The present exhaust-duct system is more extensive, handles larger volumes of gas, and is more closely confined than those in use at the time of the Air Corps tests and can be expected to have a higher ignition potential. Furthermore, the explosive fuel-air mixture in the induction system of carburetor-equipped engines is almost certain to be ignited by the hot exhaust valves and gases when the engine is forcibly stopped. The exhaust-disposal system thus causes a backfire and creates an additional hazard. The British recognize this danger and inject part of the fire-extinguishing medium into the induction system to reduce this possibility (reference 5). It would therefore be expected that the exhaust system is an important crash-fire ignition source at the present time, although no convincing data on this conclusion are available for modern aircraft. One of the primary purposes of crash-fire studies should be to obtain additional information concerning the relative importance of the ignition sources.

Primary causes of fire. - For the purpose of this discussion, the primary cause of a fire is defined as any malfunction or failure that results in the proximity of a combustible to an ignition source, or the creation of an ignition source within effective proximity of a combustible material. Engine failures are considered to include only failures of the engine assembly as delivered by the engine manufacturer and do not include the entire power-plant installation. The failure of maintenance or operating personnel to maintain equipment properly or to operate equipment according to established rules is considered a personnel failure. A basic engine, airframe, or accessory design feature that results in recurring failure or undesirable event, even though operation is by experienced personnel and according to normal procedure, is designated a design fault.

The following table shows the relative frequency with which the various primary causes were responsible for flight fires:

Cause	Cases	Percent of known cases
Engine failure	43	36
Electrical-power-system failure	23	19 $\frac{1}{2}$
Exhaust-system failure	8	7
Design fault	8	7
Air-conditioning-system failure	7	6
Personnel failure	7	6
Fuel-plumbing-system failure	5	4
Propeller failure	4	3 $\frac{1}{2}$
Lubricating-oil-system failure	2	2
Hydraulic-system failure	1	1
Other	11	8
Unknown	16	
Total cases	135	

The percentages show that engine failures were responsible for the largest number of flight fires. A study of the number of fires caused by engine failures and the revenue hours flown per year (reference 4) shows that the number of engine-failure fires per 100,000 revenue hours gradually decreased from approximately 0.4 in 1938 to 0.064 in 1945, increased to 0.525 in 1946 and decreased slightly to 0.5 in 1947. The sudden increase in engine-failure fires was probably due to the simultaneous introduction of new engines and airframes in air-transport service. The gradual increase in reliability to be expected as the troubles attending the introduction of new models are eliminated will reduce the number of engine-failure fires.

The following system failures or cause factors resulted in ground fires:

Cause	Cases	Percent of known cases
Fuel-plumbing-system failure	22	30
Design fault	18	25
Electrical-power-system failure	8	11
Personnel failure	7	9 $\frac{1}{2}$
Hydraulic-system failure	5	7 $\frac{1}{2}$
Exhaust-system failure	3	4
Air-conditioning-system failure	3	4
Engine failure	2	3
Fuel-storage-system failure	1	1 $\frac{1}{2}$
Other	4	5 $\frac{1}{2}$
Unknown	9	2
Total	82	

The largest number of ground fires were the result of fuel-plumbing failures and inadequate design. Fires attributed to the design factor were predominantly gasoline-fed backfire-ignited fires, which attended the starting operation and are characteristic of the engine-induction-system design. Inasmuch as the frequency of backfire-ignited fires has decreased, the design-fault percentage is too high to be representative of current conditions.

The failures of the fuel plumbing are typical for standard tubing systems. The following examples are taken from operator's reports: Primer line failure, pressure-gage line failure, leaky primer connection, loose carburetor vent line, leaking hose connection, leaking oil dilution solenoid valve, fuel-flowmeter line failed, heater fuel connection loose, fuel-pump leakage, fuel-pressure line chafed through, and T-fitting in vent line broken. The number of fuel-plumbing-system fires per unit of revenue hours has not shown a consistently decreasing trend, although introduction of the flexible-hose assembly did reduce the fuel-line troubles (reference 4). Plumbing failures are therefore concluded to be the most important single source of ground fires.

The primary causes of crash fires are as follows:

Cause	Cases	Percent of total
Fuel-storage-system failure	3	5
Engine failure	1	$1\frac{1}{2}$
Hydraulic-system failure	1	$1\frac{1}{2}$
Fuel-plumbing-system failure	1	$1\frac{1}{2}$
Unknown	55	$90\frac{1}{2}$
Total cases	61	

Although the unknown percentage is so large that other percentages in the table are not numerically significant, it is noted that failure of the fuel tanks is one of the causes of crash fires. British studies (reference 5) show that fuel spillage is an important factor in crash fires and specific proposals for reducing the hazard have been made. These proposals include the use of more crash-resistant fuel tanks, removing plumbing connections from the bottom of the tanks, routing plumbing and locating tanks in zones where the possibility of damage is reduced, and installing automatic shut-off valves to stop the flow from broken fuel lines.

In determining the over-all significance of fuel-plumbing and fuel-storage system failures, flight, ground, and crash fires must all be considered. The data show that 30 percent of ground fires and 4 percent of flight fires are caused by fuel-plumbing failures. The quantitative importance of these failures for crash fires is unknown but is probably considerable. It is thus apparent that the fuel-plumbing system requires additional development, better maintenance, or both, if the number of fires attending such failures is to be significantly reduced. The development of a better fuel-plumbing system that could be applied to aircraft now in use without major modifications in airplane configuration would lead to an immediate reduction in the fire hazard.

Prevalent combinations of initial combustible, ignition source, and cause. - Data on initial combustibles, ignition sources, and causes of fires have been presented. The significant combinations of initial combustible, ignition source, and primary cause for ground and flight fires are indicated in figures 1 and 2, respectively.

Such patterns were not prepared for the crash fires because of the small number of known cases. When gasoline was the initial combustible in flight fires (fig. 2), it was usually ignited by either the exhaust-disposal system or a backfire and the cause was some form of engine failure. When gasoline was the initial combustible in ground fires (fig. 1), there were two typical fire patterns: gasoline ignited by various ignition sources and caused by fuel-plumbing failures, and gasoline ignited by a backfire and caused by inherent characteristics of the induction-system design. Lubricating-oil flight fires (fig. 2) were generally ignited by the exhaust system and the oil was spilled by an engine failure. Of the flight fires in which the initial combustible could have been either gasoline or lubricating oil (fig. 2), most of the fires were started by the exhaust system and all of them were caused by engine failure. Ground fires that started with the lubricating oil were ignited by the exhaust system, but the primary cause of the fire was generally unknown.

Considering both gasoline and lubricating oil as initial combustibles, the records indicate that the exhaust system is the most important ignition source for gasoline and oil flight fires and that engine malfunction or breakup is the most frequent cause of such fires. Out of 56 such flight fires, 28 were ignited by the exhaust system and 35 were caused by engine failure or breakup. At least half of the ground fires involving hydraulic fluid were ignited by the exhaust system and failure of the hydraulic system was usually responsible.

In considering remedial measures that might be applied to the airplane-fire problem, the following methods of approach are possible: Eliminate the combustible or reduce its inflammability; eliminate the ignition source or reduce its ignition potential; eliminate the oxygen in the volume by providing an inert gas to dilute the oxygen concentration below inflammable limits; eliminate the primary cause of the fire; or find means of reducing the hazard associated with the primary cause. Combinations of two or more of these measures may offer a more practical solution in a particular problem than the full use of a single measure.

In applying these measures to the typical fires described, it is immediately obvious that the fuel cannot be eliminated as a combustible, although a fuel less inflammable than gasoline might be substituted. The problems associated with such a solution are being studied by various aviation organizations. The possibility of a relatively noninflammable lubricating oil cannot be overlooked and the commercial announcement of less-inflammable hydraulic fluids indicates that some progress is being made toward this objective. Complete elimination of the exhaust-disposal system as an

ignition source appears remote, but measures that would reduce its ignition potential must be found and tested. Experience has shown that the hazard of backfires as an ignition source can be further reduced by the use of direct fuel injection. Inerting of zones occupied by fuel lines may offer some advantage for flight and ground operation, but little advantage during crash conditions. The possibility of eliminating fires by the use of a more reliable power plant and fuel-plumbing system should certainly be considered, because greater engine plumbing reliability would also result in greater operational reliability. Use of lower power ratings on current engines and closer engine supervision to shut down engines giving indications of incipient failure may be possible partial solutions. Use of direct fuel injection instead of a carburetor system to eliminate a fuel-air mixture in the impeller housing would eliminate the hazard attending impeller failures, loose intake pipes, and failures in which the fuel-air mixture escapes into the nacelle. This system has reduced induction-system fires on at least one model of military airplane.

The patterns of flight fires involving electrical insulation (fig. 2) show that the ignition source is usually electrical. Failures listed as "other" are communications and electrical-instrument system failures; therefore, about 80 percent of electrical flight fires are caused by failure of electrical-power system, communication system, or electrically operated instruments. Patterns for ground fires (fig. 1) involving electrical insulation are similar to flight patterns. All possible means of reducing the electrical-insulation fire hazard must be studied, although the most promising measures are the removal of inflammable material, which is already in progress, and better maintenance and design to increase the general reliability of electrical systems.

The data indicate that no particular combinations of ignition source and cause predominated when the initial combustible was unknown. Apparently the known cases constitute a representative sample and the results are dependable for the flight-and ground-fire conditions.

General remarks. - The outstanding feature shown by the tables of crash-fire results is the large unknown percentages. In approximately 90 percent of the cases, the initial combustible, ignition source, or cause were unknown. Two reasons for this situation can be given: (1) Nearly all crash fires either initially or finally involve gasoline and thus develop rapidly into a fire of such magnitude that all evidence of the initial combustible or breakup that preceded the start of the fire is destroyed. (2) The accident was investigated to

determine its cause, not why or how a fire ensued. When the crash was caused by fire, the investigation generally indicated the initial inflammable and allied data; when fire was incidental, little information concerning the fire factors was noted or determined. Additional information concerning the causes and the physical mechanism of crash fires is needed if the hazard is to be reduced. Inasmuch as future accidents can provide operational information, each crash accident, regardless of whether fire did or did not occur, should be studied to obtain data that will relate the occurrence and the spread of fire to airplane design and operation.

SUMMARY OF RESULTS AND CONCLUSIONS

An analysis of CAA and CAB commercial transport airplane fire records shows that:

1. Gasoline was most frequently the initial combustible in flight and ground fires and is considered to be the most hazardous of the combustibles.
2. Although electrical-ignition sources are the most frequent flight-fire ignition source by a small margin, the exhaust system is concluded to be the most hazardous ignition source because it is necessarily located near the lubricating-oil and gasoline-plumbing systems and the resulting fires are relatively severe. The electrical-ignition sources usually involve only the electrical insulation and result in small-volume fires. The exhaust system was found to be the most frequent ground-fire ignition source.
3. Engine failures were the most frequent cause of the union of combustible and ignition source that resulted in flight fires.
4. Fuel-plumbing-system failures were the most frequent cause of fires occurring during ground operation.
5. The evidence concerning crash fires was not sufficiently extensive to provide information concerning the factors that affect the start and the spread of fire. In order that future records may be more useful, all crash accidents should be studied to determine why fire does or does not occur and to establish data that relate the occurrence and the spread of fire to airplane design and operation.

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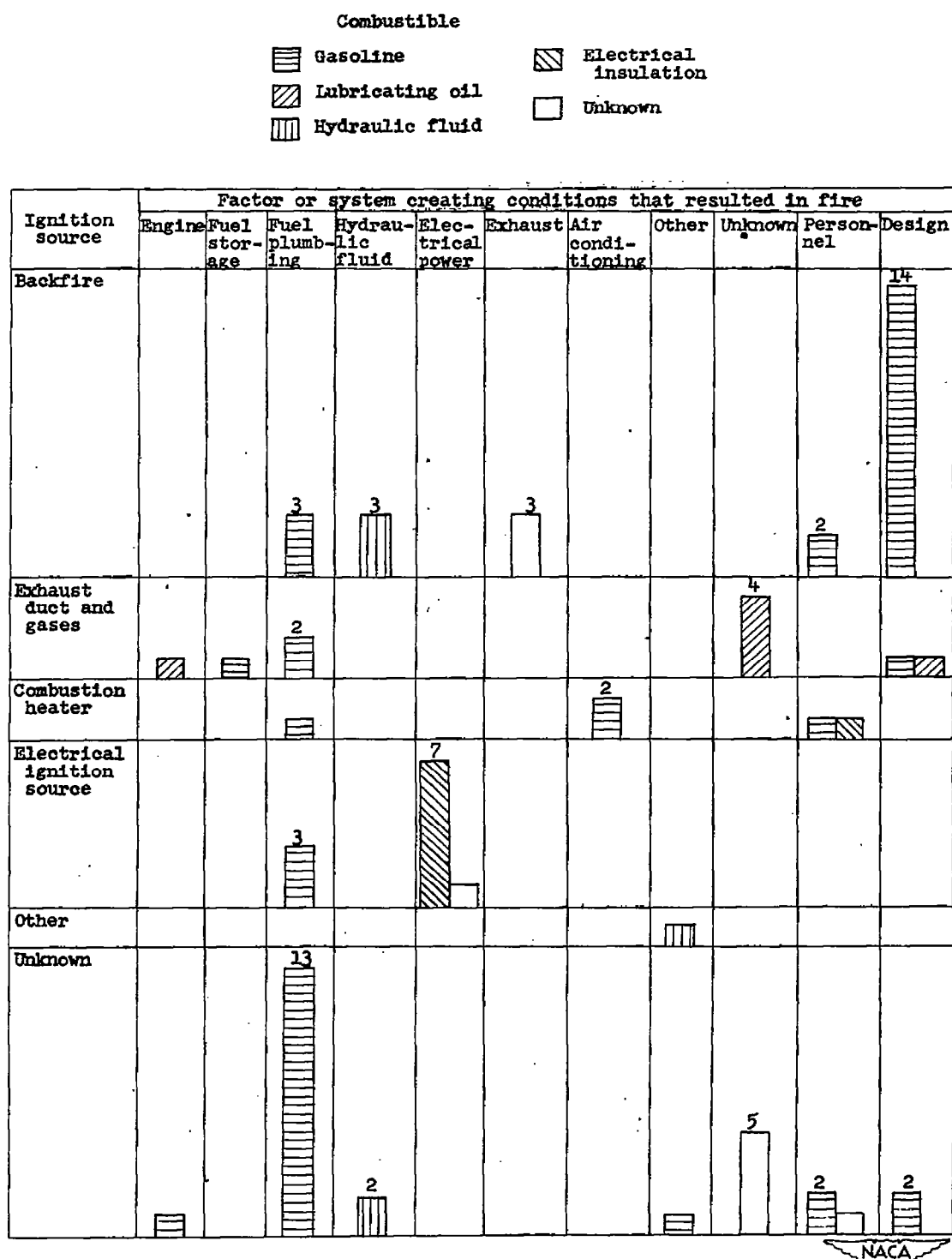


Figure 1. - General pattern of initial combustibles, ignition sources, and primary causes of ground fires in multiengine commercial-transport-type aircraft.

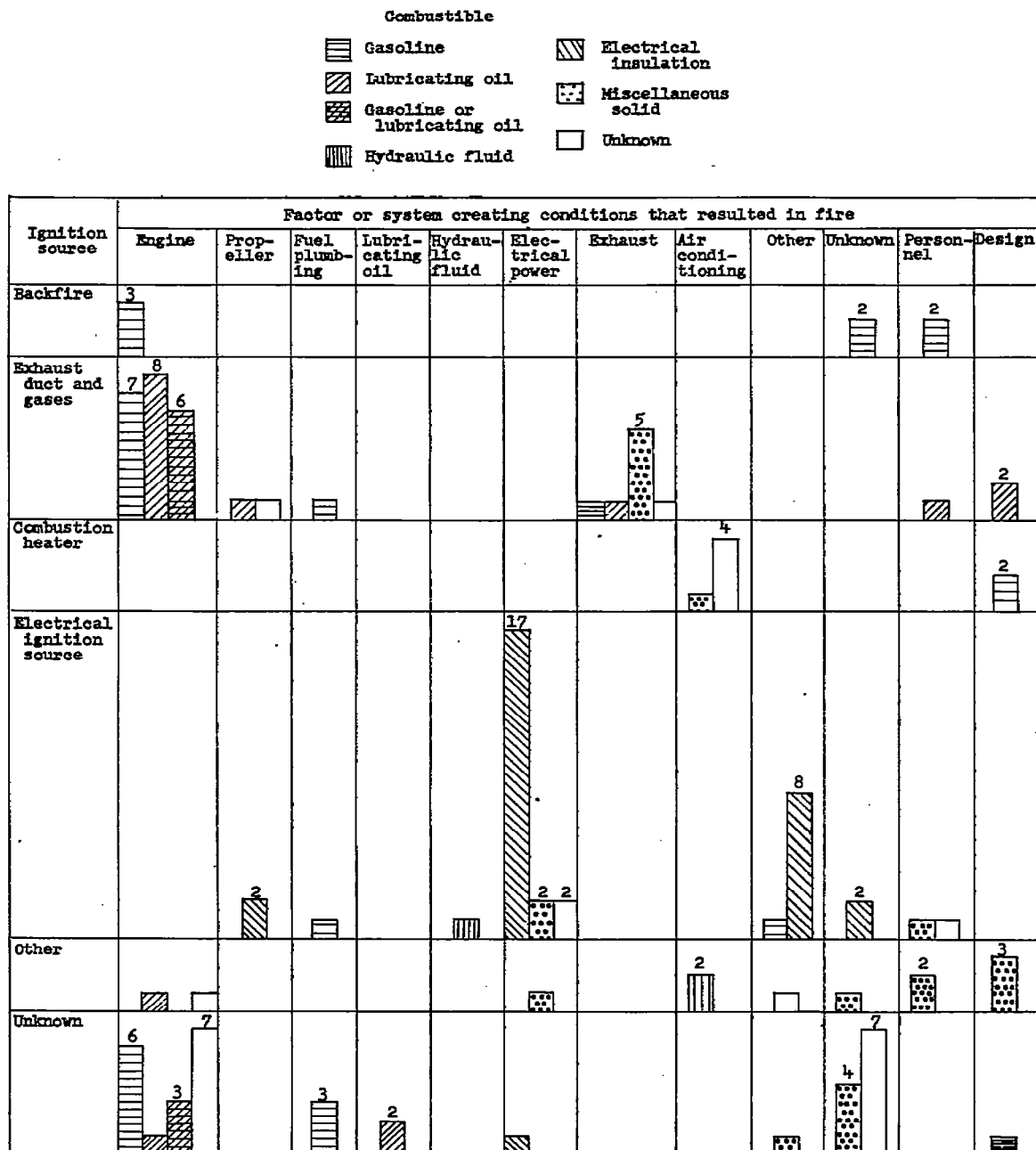


Figure 2. - General pattern of initial combustibles, ignition sources, and primary causes of flight fires in multiengine commercial-transport-type aircraft.

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